Original Article

Effect of clear aligners and Z-spring appliance on anterior crossbite correction and quality of life in the mixed dentition: a randomized clinical trial

Buse Nur Gok[a]; Ahmet Yalcin Gungor[b]; Ozge Erken Gungor[c]

ABSTRACT

Objectives: To compare the efficacy of clear aligners and Z-spring (ZS) appliances in treating dental anterior crossbite (AC) during the mixed dentition period.

Materials and Methods: Thirty patients (7–12 years) with Angle Class I occlusion and isolated pseudo-Class III AC were randomly assigned to clear aligners (Group A, n = 15) or ZS appliances (Group B, n = 15). Outcomes were evaluated based on duration, cephalometric changes, model analysis, and oral health-related quality of life (OHRQoL), assessed using the Child Oral Health Impact Profile-Short Form-19 (COHIP-SF-19).

Results: AC was successfully corrected in all patients. Treatment duration was significantly shorter in Group B (48.4 ± 27 days) than in Group A (96.3 ± 22.7 days) ($P < .05$). U1–NA angle increased by 5.9° and overjet by 4 mm in Group A; in Group B, U1–NA increased by 7.7° and overjet by 4.2 mm ($P < .01$). Intergroup cephalometric changes (ΔT1–T0) were not significant ($P > .05$). In Group A, incisal and gingival arch depths increased significantly (2.6 mm and 1.17 mm, respectively; $P < .001$), whereas no significant changes occurred in Group B ($P > .05$). COHIP-SF-19 scores were comparable ($P > .05$).

Conclusion: Clear aligners and ZS appliances were effective in treating dental AC, achieving normal overjet relationships. However, ZS appliances may cause greater tipping, whereas clear aligners facilitate tipping, alignment, and bodily movement. Treatments demonstrated comparable effects on OHRQoL of children. This study provides a foundation for future research on different appliances for managing AC in the mixed dentition. (*Angle Orthod*. 2025;00:000–000.)

KEY WORDS: Anterior crossbite; Cephalometric analysis; Clear aligner; Z spring appliance; Model analysis; Quality of life

INTRODUCTION

Skeletal and dental malocclusions during growth and development can negatively affect dentofacial esthetics and function. Anterior crossbite (AC) is one of the most common malocclusions in the mixed dentition period, with a prevalence ranging from 2.2% to 11.9%.[1–4] AC is defined as the lingual positioning or reverse overjet of the maxillary incisors relative to the mandibular incisors in centric occlusion.[5] Dental AC typically results from abnormal axial inclination of incisors in patients with normal skeletal structure and a Class I molar relationship. In contrast, skeletal AC as seen in true Class III malocclusion, involves maxillofacial discrepancies such as mandibular prognathism, maxillary retrusion, or both. A subtype of dental AC, pseudo-Class III malocclusion, is typically caused by premature anterior contact, resulting in a functional mandibular shift. It can be distinguished from true skeletal Class III by a shift that corrects when the mandible is guided into centric relation.[5,6]

Untreated AC can interfere with jaw growth and potentially exacerbate skeletal discrepancies by restricting maxillary development or promoting excessive mandibular

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growth.[5] Additionally, it may progress to a true Class III malocclusion and contribute to temporomandibular joint dysfunction.[6] Therefore, early diagnosis and intervention are critical for optimizing treatment outcomes.

Patients with AC may benefit from interceptive orthodontics, defined as procedures aimed at eliminating or reducing the severity of developing malocclusion. The primary goal of these interventions is to re-establish normal occlusion and positive overjet.[7]

A crossbite in the anterior region is often a significant source of esthetic concern for children and their parents. Treatment must aim to improve esthetics, maintain function, and support normal skeletal development. Various treatment modalities are available, including inclined planes, habit-breaking appliances, reverse crowns, clear aligners, removable and fixed appliances.[8,9] Among these, removable Z spring (ZS) appliances and fixed systems are commonly used.[5] However, their metallic appearance can raise esthetic concerns and, therefore, may affect socioemotional well-being.

Recent advances in clear aligners provide an esthetic alternative for AC management. These aligners not only address functional and esthetic issues but can also improve oral health-related quality of life (OHRQoL) of patients during treatment.[10] Evaluating the impact of treatment modalities on OHRQoL is essential for overall development of children, including nutrition, education, and socialization.[11]

Despite increasing use of clear aligners, studies comparing their efficacy to that of ZS appliances for AC correction remain lacking. Data on treatment duration, cephalometric changes, dental arch parameters, and their impact on children's quality of life are also limited. This study aimed to compare the effectiveness of clear aligners and ZS appliances in managing AC during the mixed dentition period and to evaluate their effects on OHRQoL.

MATERIALS AND METHODS

Ethical Approval and Funding

This study received ethical approval from the Akdeniz University Faculty of Medicine Clinical Research Ethics Committee (Decision No.189, June 21, 2023) and the Turkish Ministry of Health, Medicines and Medical Devices Agency (Approval No. E-68869993-511.06.01.01.01-1195871, August 17, 2023). Funding was provided by the Akdeniz University Scientific Research Projects Coordination Unit (Project ID: TDH-2024-6420).

Sample Size Calculation

G*Power 3.1 (Franz Faul, University of Kiel, Germany) software was used to determine the required sample size. Based on an effect size of Cohen's d = 1.25, alpha of 0.05, and power of 90%, a minimum of 15 participants per group (n = 15) was determined to be necessary.

Participant Selection Criteria

This prospective study was conducted at the Pediatric Dentistry Department of Akdeniz University, between June and November 2024. A total of 59 patients with AC were evaluated, and those not meeting the inclusion criteria were excluded. Thirty cooperative children, aged 7–12 years with the following inclusion criteria were enrolled: mixed dentition, Class I molar relationship, and anterior crossbite involving at least one permanent incisor. All participants had Class I molar relationships with isolated pseudo-Class III AC without skeletal discrepancies, no prior orthodontic treatment, maxillofacial trauma, or systemic conditions affecting treatment.

Randomization, Allocation Concealment, and Blinding

This study adhered to the Consolidated Standards of Reporting Trials guidelines.[12] Patients were randomly assigned to either the clear aligner (Group A) or the ZS appliance group (Group B) using block randomization (Figure 1). An independent researcher, not involved in patient treatment or outcome assessment, used sealed envelopes to randomly allocate participants and ensure concealment. The same clinician performed the treatments and the outcome measurements, making operator blinding unfeasible. However,

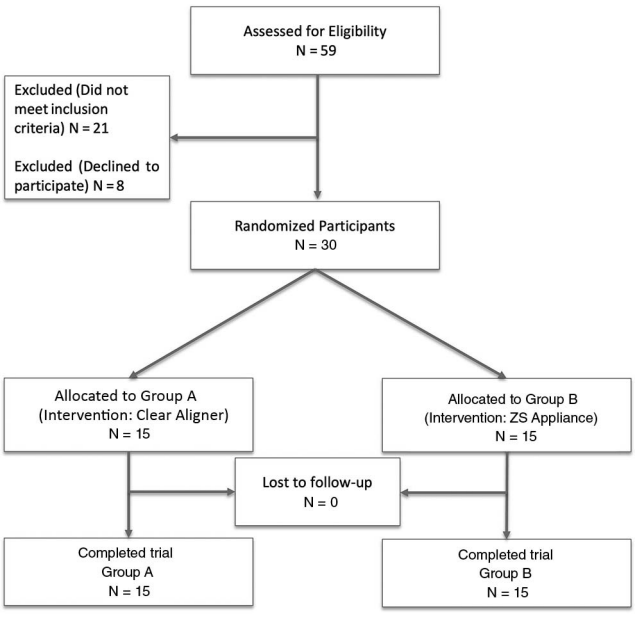

Figure 1. Study workflow.

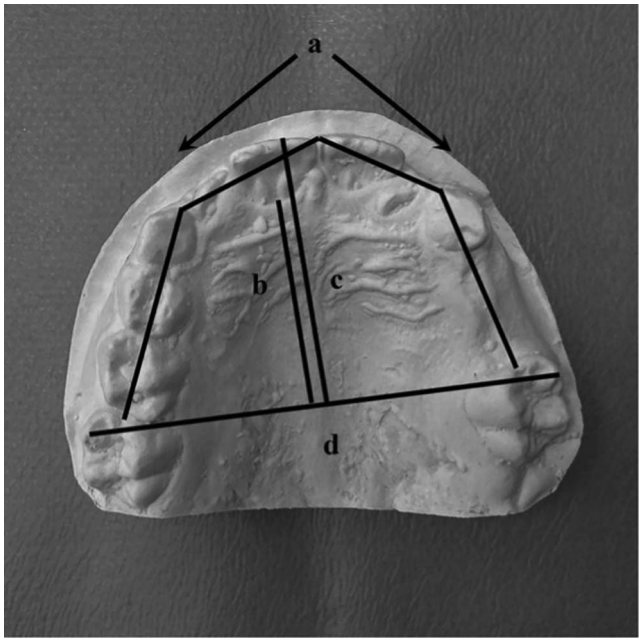

Figure 2. Parameters measured for the model analysis: (a) arch length, (b) gingival arch depth, (c) incisal arch depth, (d) intermolar distance.

to minimize measurement bias, all records were de-identified and coded before analysis, ensuring that the examiner could not discern to which treatment group each record belonged.

Data Collection and Measurements

Data collected at pretreatment (T0) and post-treatment (T1) included cephalometric radiographs, model analysis, and the Child Oral Health Impact Profile-Short Form-19 (COHIP-SF-19) questionnaire. Standardized intraoral and extraoral photographs, and cephalometric radiographs (74 kW, 6 mA, 18.7 s) were also obtained. Patients were positioned using a cephalostat to ensure the Frankfurt Horizontal Plane was parallel to the floor. Digital images were analyzed using Dolphin Imaging software (V11.95, Chatsworth, USA). A 10-mm reference length was used for calibration. The researcher identified landmarks, and the software recorded measurements. Alginate impressions (Tropicalgin, Zhermack S.p.A, Italy) were taken at T0 and T1 using appropriately sized trays. Plaster models were made for model analysis and appliance fabrication. Upper arch parameters were measured with a digital caliper (0.01-mm accuracy) (Figure 2). Incisal and gingival arch depths were measured perpendicularly from the incisal edge and palatal gingiva of the crossbite tooth to a line connecting the mesiobuccal cusps of the first permanent molars, using a protractor and digital caliper. Incisor tipping was calculated as the difference between incisal and gingival arch depths. Each model was measured twice, and the mean values were recorded by a blinded examiner.

Clinical Applications

Initial procedures were identical for both groups. In Group A, customized clear aligners (Crystal Aligner, Orthoclear, Antalya) were fabricated, ranging from 7 to 12 per patient depending on malocclusion severity, and were limited to the upper arch as correction involved only the maxillary incisors. Attachments were bonded to the incisor in crossbite, the adjacent central incisor, and both first permanent molars (midbuccal/labial surfaces). In Group B, ZS appliance was used, featuring a protrusion spring for labial movement of the incisors, an acrylic plate for bilateral posterior bite opening, Adams clasps on the first permanent molars, and a passive labial arch. Representative intraoral photographs illustrate clinical application of the clear aligners (Group A, Figure 3) and ZS appliances (Group B, Figure 4).

Patient Instructions and Follow-Up

Patients were instructed to wear either the clear aligners or the ZS appliance for at least 22 hours per day, removing them only for meals and oral hygiene procedures. Aligners were changed every 10 days during clinical visits, at which adaptation and tooth movement were assessed. In Group B, springs were activated every 10 days until normal overjet was achieved. Treatment continued until positive overjet was established. At T1 in both groups, all measurements were recorded, and the COHIP-SF-19 was administered (Appendix 1). Subsequently, the final aligners or ZS appliances were worn passively for 1 week to serve as short-term retainers.

Collection of Quality-of-Life Data

At the final session, patients in both groups independently completed the COHIP-SF-19 questionnaire without parental assistance. The researcher was present to answer any questions. Before administration, children were informed about the objective of the questionnaire and the importance of providing independent responses. The questionnaire consists of 19 items categorized into three subscales: oral health, functional health, and social-emotional well-being. Responses are recorded on a five-point Likert scale. The total score varies between 0 and 76, with higher scores indicating lower OHRQoL.

Statistical Analysis

Statistical analysis was performed using MedCalc (v23.0.8) and SPSS (v23.0). Numerical data are

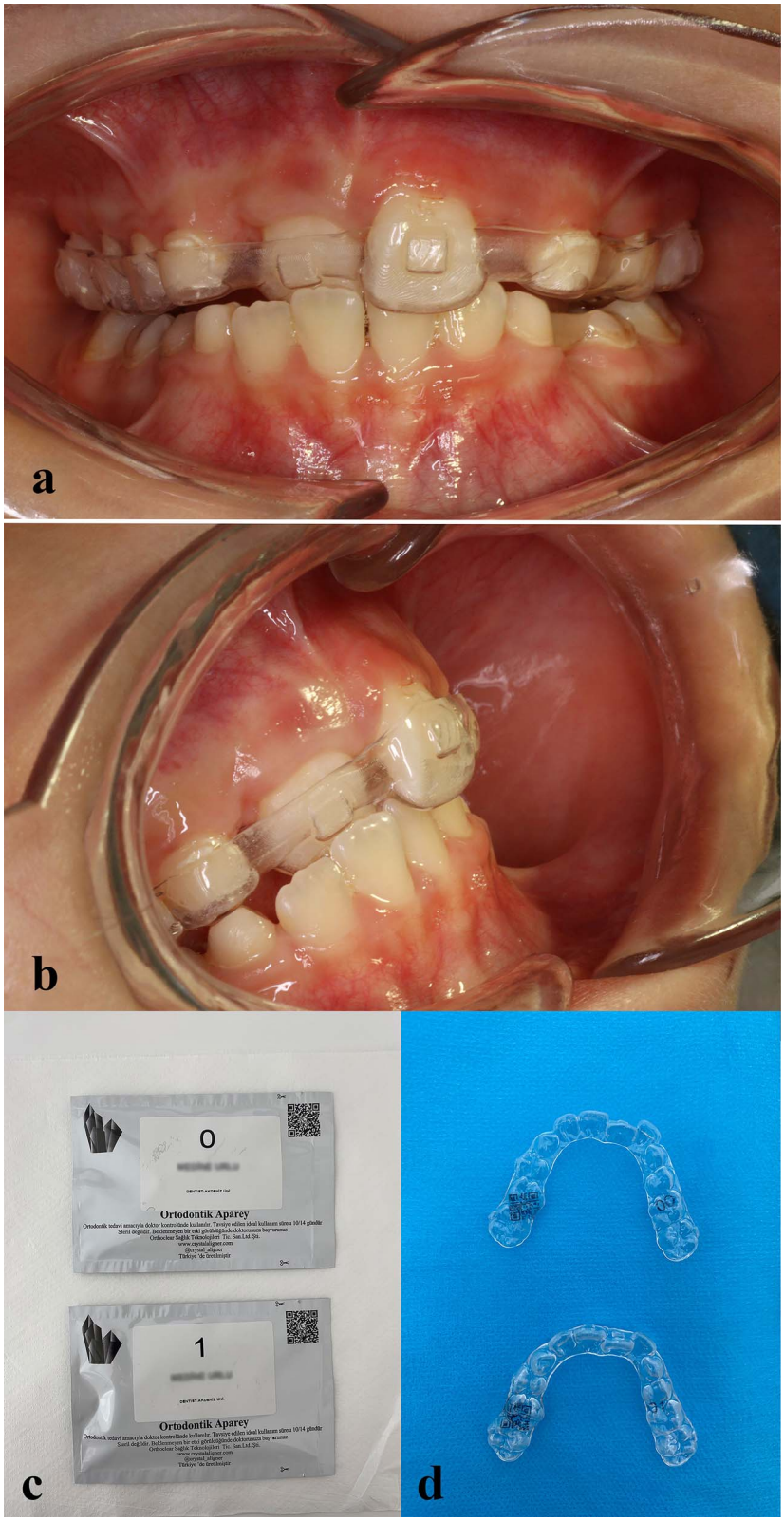

Figure 3. Clear aligners at T0: (a) frontal view, (b) lateral view, (c) packaging of the aligners as received from the laboratory, (d) aligner design.

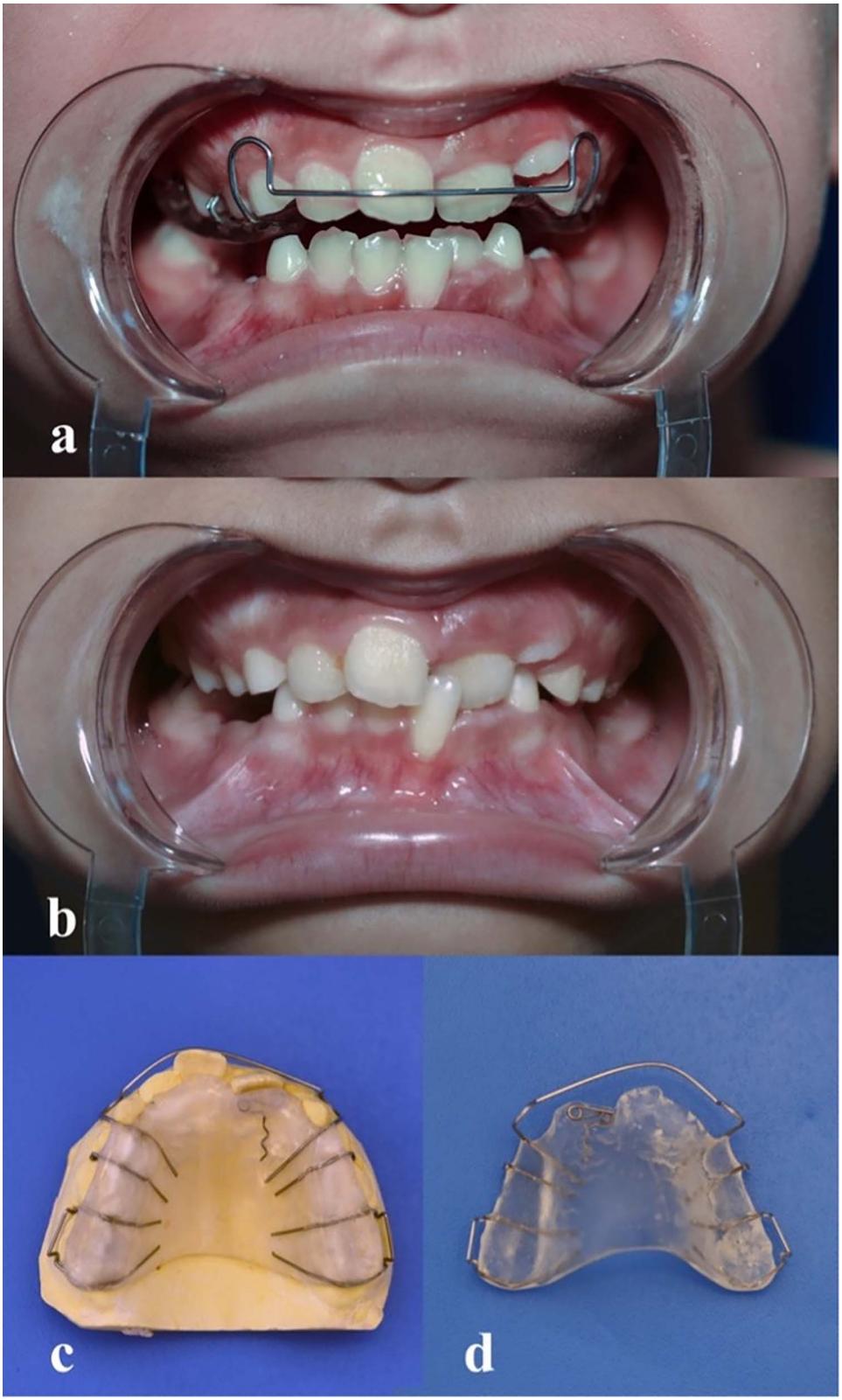

Figure 4. (a) ZS appliance at T0, (b) intraoral view of a patient from Group B at T0, (c) laboratory-fabricated appliance, (d) appliance design.

Table 1. Demographic Data of Study Patients[a]

	Group A (Clear Aligner)			Group B (ZS)			Total N = 30	
	Female	Male	Total (N)	Female	Male	Total (N)	Female (n, %)	Male (n, %)
Number of Patients (n)	6	9	15	4	11	15	10 (33.3)	20 (66.7)
Age (y), Mean ± SD	9.75 ± 2.29	9.65 ± 1.91	9.79 ± 2.03	10.02 ± 1.82	9.90 ± 2.04	9.8 ± 2.17	9.42 ± 1.6	

[a] Mean indicates average; SD, standard deviation.

presented as mean ± standard deviation or median (interquartile range), and categorical variables as percentages. Normality was assessed with the Kolmogorov–Smirnov test. Between-group comparisons used the Student's *t*-test (normal data) or Mann–Whitney *U* test (non-normal data), while within-group comparisons used the paired *t*-test or Wilcoxon test. All tests were two-tailed, with significance set at $P < .05$.

RESULTS

Demographic Characteristics and Treatment Duration

Table 1 shows that Group A (mean age: 9.79 ± 2.03 years) included six female and nine male patients, whereas Group B (mean age: 9.80 ± 2.17 years) consisted of four female and 11 male patients. The overall mean age was 113 ± 19.2 months, with 33.3% female and 66.7% male patients. Group A required significantly longer treatment duration (96.3 ± 22.7 days) than Group B (48.4 ± 27 days, $P < .001$). No significant differences in treatment duration were observed between age subgroups ($P > .05$), but Group A consistently required longer treatment across both age categories (Table 2). Figures 5 and 6 present intraoral photographs of representative patients from Groups A and B, respectively, at T0 and T1, illustrating treatment-related dental and occlusal changes.

Cephalometric Analysis

Pretreatment cephalometric values showed no significant differences between Groups A and B for most parameters ($P > 0.05$) (Table 3), except for IMPA, which was higher in Group A (98.17 ± 5.33°) than Group B (92.47 ± 8.68°) ($P = .04$). Within-group comparisons (Table 4) revealed significant increases between T0 and T1 in Group A for L1-NB distance ($P < .001$), overbite ($P = .04$), overjet ($P < .001$), U1-NA angle ($P < .001$), U1-NA distance ($P < .05$), and U1-Palatal Plane angle ($P < .001$). Similarly, in Group B (Table 5), significant changes between T0 and T1 included increased overjet (+4.2 mm, $P < .001$), U1-NA angle (+7.7°, $P < .001$), and U1-NA distance (+3.4 mm, $P < .001$), as well as U1-Palatal Plane angle (+6.1 mm, $P < .001$). The interincisal angle decreased significantly (−5.3°, $P < .001$). A direct comparison of cephalometric changes (ΔT1-T0) between groups revealed no significant differences for any parameter ($P > .05$) (Table 6).

Model Analysis

Model analysis findings for each group (Table 7) indicated significant increases in gingival arch depth, incisal arch depth, and incisor tipping in Group A ($P < .001$), whereas arch length and intermolar distance showed no significant changes ($P > .05$). No significant differences were observed between T0 and T1 for any parameter in Group B ($P > .05$). Comparing ΔT1-T0 changes (Table 8), revealed a significant difference only for incisor tipping ($P = .04$), with a greater increase in Group A (+1.47 mm) than Group B (+0.41 mm).

Table 2. Comparison of Treatment Protocols Between Group A and Group B in Treatment Duration by Age Categories

Variable	Group A	Group B	Difference (95% CI)	*P* Value
Treatment duration (d), Mean ± SD (patients aged 7–10 y)	94.9 ± 27	41.8 ± 25.7	53.1 (27.5 to 78.7)	$P < .01$
Treatment duration (d), Mean ± SD(patients aged > 10 y)	99.2 ± 11.7	58.3 ± 28.2	40.8 (10.1 ± 71.6)	$P < .01$

Variable	7–10 y	>10 y	Years Difference (95% CI)	*P* Value
Treatment duration (d) in Group A, Mean ± SD	94.9 ± 27	99.2 ± 11.7	4.3 (−23.4 to 32)	.74
Treatment duration (d) in Group B, Mean ± SD	41.8 ± 25.7	58.3 ± 28.2	16.6 (−13.8 to 46.9)	.26

[a] CI indicates confidence interval; mean, average; SD, standard deviation.

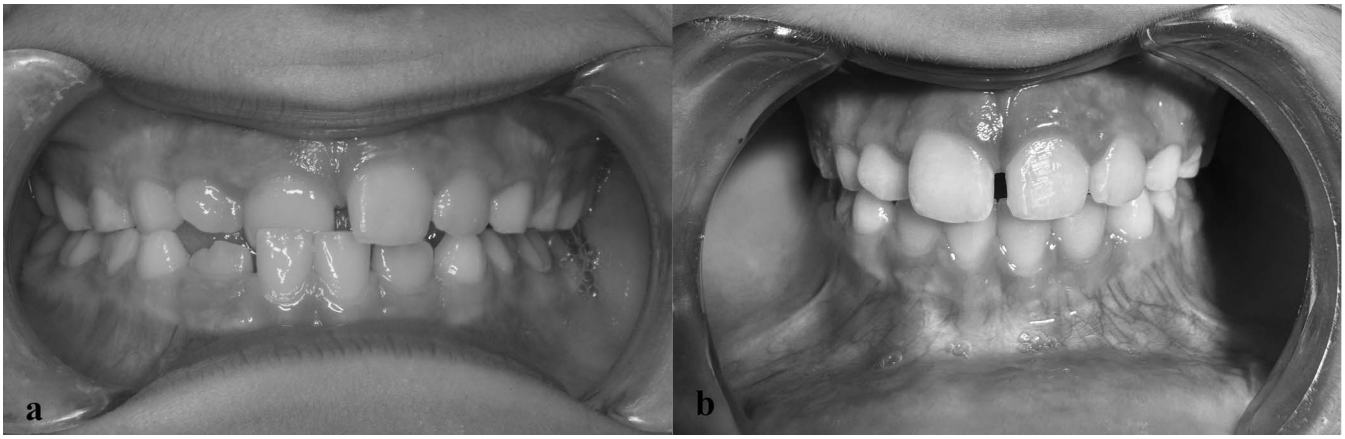

Figure 5. Patient treated with clear aligners: (a) anterior crossbite (T0), (b) normal anterior occlusion (T1).

Quality-of-Life Assessment (COHIP-SF-19)

Total COHIP-SF-19 scores (Table 9) showed no significant difference between Group A (15 ± 5.6) and Group B (14 ± 8.3) ($P = .70$). Similarly, no significant differences were found in the Oral Health ($P = .55$), Functional Health ($P = .29$), or Social-Emotional Well-being ($P = .53$) subdomains.

DISCUSSION

There is a lack of clinical studies comparing the efficacy of clear aligners and ZS appliances in the treatment of AC during the mixed dentition period. This study was the first to address this, providing direct comparisons between these two treatment modalities. The results of this study contribute to the existing body of knowledge by offering comparative data on these parameters, providing new insights into the clinical application of clear aligners and ZS appliances.

The optimal age for AC treatment is 8–11 years, corresponding to the active eruption phase. This study included patients aged 7–12 years, with mean ages of 9.79 years (Group A) and 9.8 years (Group B), ensuring similar developmental stages between groups. Randomization ensured comparability, but gender imbalance prevented sex-based analysis. Future studies with gender-balanced groups may provide further insights into potential differences in treatment responses.

Group A required a significantly longer treatment duration (47.9 days more). This may have been due to the staged nature of tooth movement, controlled force application, and the 10-day aligner change protocol, which supports biologically appropriate forces and aims to balance treatment efficiency with optimal tissue response in younger patients. In contrast, the ZS appliance produced faster results, likely due to higher initial forces, but this may compromise long-term stability without retention. However, as this study did not include post-treatment follow-up, potential differences in relapse could not be assessed. Further studies are needed to evaluate long-term outcomes.

An initial hypothesis suggested that treatment duration might increase with age. Although older patients

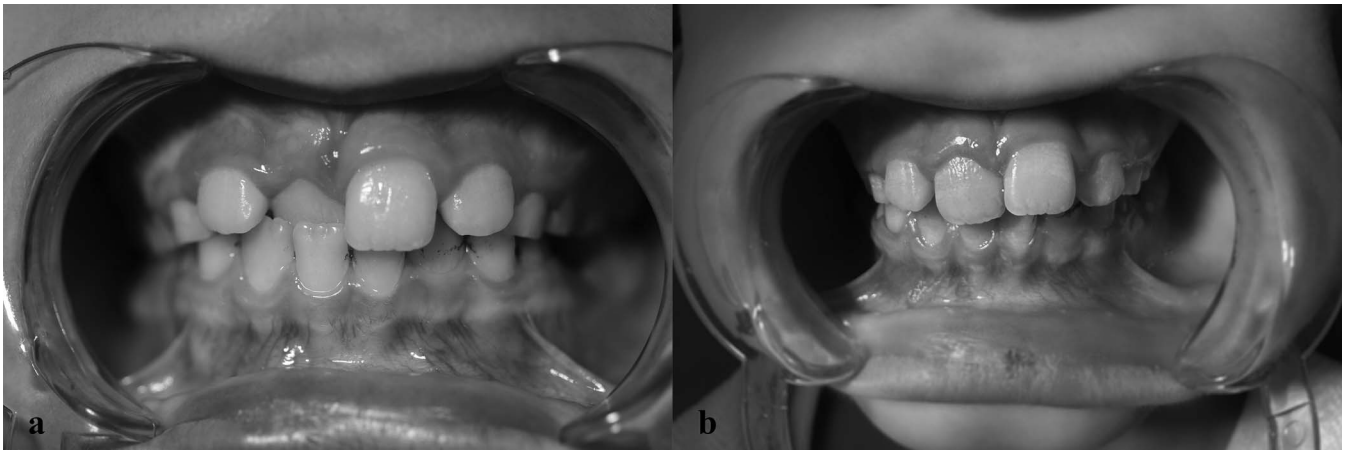

Figure 6. Patient treated with a ZS appliance: (a) AC (T0), (b) normal anterior occlusion (T1).

Table 3. Comparison of Pretreatment (T0) Cephalometric Measurements Between Group A and Group B[a,b]

Variable	Group A	Group B	Difference (95% CI)	*P* Value
SNA (°)	81.1 ± 4.96	80.6 ± 2.47	−0.48 (−3.46 / 2.5)	.73
SNB (°)	78.8 ± 3.48	78.5 ± 2.82	−0.26 (−2.63 / 2.1)	.82
ANB (°)	2.32 ± 2.47	2.13 ± 2.32	−0.18 (−1.98 / 1.6)	.83
Wits (mm)[b]	−1.8 (−2.88 / 0.25)	−3.8 (−5.4 / 1.4)	−1.7 (−3.8 / 0.4)	.11
FMA (°)	27.74 ± 3.83	28.25 ± 6.49	0.5 (−3.48 / 4.49)	.79
SN-GoGn (°)	30.77 ± 3	33.3 ± 5.3	2.57 (−0.71 / 5.84)	.11
Interincisal Angle	126.4 ± 8.6	132.5 ± 9.1	6 (−0.52 / 12.7)	.07
U1-NA (°)	20.2 ± 5.9	17.1 ± 4.96	−3 (−7.2 / 1)	.13
U1-NA (mm)	0.18 ± 2.3	−0.24 ± 3.3	−0.42 (−2.56 / 1.71)	.68
U1-Palatal Plane (°)	109 ± 5.2	107 ± 6.7	−1.94 (−6.4 / 2.5)	.38
L1-NB (°)	30.54 ± 5.3	27.4 ± 5.7	−3.2 (−7.3 / 0.91)	.12
L1-NB (mm)	4.87 ± 1.6	4.7 ± 2	−0.18 (−1.53 / 1.17)	.78
IMPA (°)	98.17 ± 5.33	92.47 ± 8.68	−5.7 (−11 / −0.3)	.04
Nasolabial Angle	113.6 ± 15.9	110.5 ± 16.3	−3 (−15.1 / 8.9)	.60
Upper Lip to S-Line (mm)	−0.3 ± 2.12	0.44 ± 1.76	0.75 (−0.72 / 2.21)	.30
Lower Lip to S-Line (mm)	1.08 ± 1.8	1.36 ± 1.42	0.28 (−0.94 / 1.5)	.64
Overbite (mm)	0.04 ± 1.34	0.27 ± 0.93	0.23 (−0.63 / 1.09)	.58
Overjet (mm)[b]	−2.2 (−2.7 / −1.7)	−2.1 (−2.7 / −1.9)	−0.2 (−0.8 / 0.3)	.53

[a] All variables are presented as mean ± standard deviation, except for those marked with an asterisk.
[b] Variables presented as median and interquartile range (IQR).

showed a nonsignificant trend toward longer durations, subgroup analysis confirmed no age effect within each group. This suggested that the prolonged treatment time in Group A was primarily due to appliance mechanics rather than patient age.

Yao et al.[13] emphasized that treatment duration was a primary concern for both patients and parents, with shorter treatment times being preferable to ensure compliance. Prolonged treatment has been associated with reduced motivation and an increased risk of missed appointments. In cases where compliance is uncertain, ZS appliances may be a more suitable alternative due to their shorter treatment time.

A key limitation of this study was the inability to fully standardize appliance wear time due to its removable nature. Patients were instructed to wear their appliances for at least 22 hours daily, with compliance monitored via self-reports and clinical evaluations. However, the absence of objective verification prevented confirmation of actual wear time, potentially influencing results. Future studies should account for this limitation when evaluating treatment outcomes.

Wiedel et al.[14] compared fixed and ZS appliances, reporting an average treatment time of 6.9 months for ZS appliances, including a 3-month retention phase. In this study, which did not include a retention phase,

Table 4. Intragroup Comparison of Cephalometric Measurements at T0 and T1 in Group A[a,b]

Variable	T0	T1	Difference (95% CI)	*P* Value
SNA (°)	81.1 ± 4.96	80.6 ± 4.41	−0.51 (−2.16 / 1.14)	.15
SNB (°)	78.77 ± 3.48	78.3 ± 3.7	−0.45 (−1.8 / 0.93)	.49
ANB (°)	2.32 ± 2.5	2.28 ± 1.8	−0.04 (−0.7 / 0.6)	.89
Wits (mm)	−1.2 ± 2.3	−0.84 ± 2.4	0.35 (−0.74 / 1.45)	.11
FMA (°)	27.7 ± 3.8	27.3 ± 2.6	−0.4 (−1.9 / 1.13)	.13
SN-GoGn (°)	30.77 ± 3	31.4 ± 2.98	0.64 (−0.29 / 1.57)	.18
Interincisal Angle	126.38 ± 8.6	122.3 ± 6.5	−4.04 (−8.4 / 0.37)	.19
U1-NA (°), median (IQR)	19.5 (15.7–22.9)	27.8 (21–30.9)	5.9 (3.8 / 9.3)	$P < .01$
U1-NA (mm)	0.18 ± 2.3	2.7 ± 2.35	2.5 (0.87 / 4.16)	$P < .01$
U1-Palatal Plane (°)	109 ± 5.2	115 ± 4.9	6 (2.3 / 9.7)	$P < .01$
L1-NB (°)	30.5 ± 5.3	29.5 ± 3.9	−1 (−2.7 / 0.76)	.24
L1-NB (mm), median (IQR)	4.9 (3.95–6.1)	4 (3.2–4.9)	−0.6 (−1.5 / −0.15)	$P < .01$
IMPA (°)	98.17 ± 5.3	97.1 ± 4.9	−1.04 (−2.8 / 0.69)	.21
Nasolabial Angle	113.6 ± 15.9	115.3 ± 13.5	1.72 (−4.26 / 7.7)	.54
Upper Lip to S-Line (mm)	−0.3 ± 2.1	−0.26 ± 1.5	0.04 (−0.99 / 1.06)	.93
Lower Lip to S-Line (mm)	1.08 ± 1.8	1.09 ± 1.5	0.01 (−0.86 / 0.88)	.21
Overbite (mm)	0.04 ± 1.34	0.97 ± 1.37	0.93 (0.03 / 1.83)	.04
Overjet (mm), median (IQR)	−2.2 (−2.7 / −1.7)	2.5 (0.55 / 2.9)	4 (2.15 / 5.2)	$P < .01$

[a] CI indicates confidence interval; IQR, interquartile range; mm, millimeter.
[b] Unless otherwise specified, data are presented as mean ± standard deviation.

Table 5. Intragroup Comparison of Cephalometric Measurements at T0 and T1 in Group B[a–c]

Variable	T0	T1	Difference (95% CI)	*P* Value
SNA (°)[b]	80.1 (78.3–82.9)	82.4 (79.1–83.5)	0.17 (−0.6 / 2.5)	.33
SNB (°)[b]	79.2 (77.3–79.8)	78.8 (78–80.2)	0.35 (−0.6 / 0.9)	.57
ANB (°)[b]	2.2 (0.43–4)	2.2 (1–4.38)	0.07 (−0.4 / 0.45)	.59
Wits (mm)[b]	−3.8 (−5.4 / 1.4)	−2.6 (−4.7 / 1.4)	0.02 (−0.7 / 1.3)	.75
FMA (°)[c]	28.3 ± 6.5	28.25 ± 6.2	−0.006 (−1.5 / 1.5)	.17
SN-GoGn (°)[b]	34 (29.6–36.6)	30.7 (29.2–38.8)	0 (−1.6 / 0.45)	.72
Interincisal Angle[c]	132.5 ± 9.1	127.2 ± 8.4	−5.3 (−8 / −2.5)	$P < .01$
U1-NA (°)[b]	17.5 (12.9–22.3)	23.9 (21–31)	7.7 (6.6 / 9.5)	$P < .01$
U1-NA (mm)[c]	−0.24 ± 3.3	3.1 ± 1.9	3.4 (1.5 / 5.2)	$P < .01$
U1-Palatal Plane (°)[b]	106.4 (100–113)	110.7 (108–119)	6.1 (4.15 / 8)	$P < .01$
L1-NB (°)[c]	27.4 ± 5.7	26.2 ± 4.3	−1.15 (−2.5 / 0.17)	.08
L1-NB (mm)[c]	4.7 ± 1.2	4.5 ± 1.5	−0.15 (−0.6 / 0.3)	.48
IMPA (°)[c]	92.5 ± 8.7	91.2 ± 7.5	−1.25 (−3 / 0.5)	.15
Nasolabial Angle[b]	111.8 (99–124)	111.8 (101–123)	0.65 (−1.05 / 5.9)	.37
Upper Lip to S-Line (mm) [b]	0.2 (−0.45 / 0.97)	0.1 (−1 / 2.4)	0 (−0.4 / 0.5)	.90
Lower Lip to S-Line (mm) [b]	0.8 (0.3–2.3)	0.5 (−0.1 / 2.5)	0 (−0.75 / 0.5)	.76
Overbite (mm)[b]	−0.2 (−0.3 / 0.75)	0.9 (−0.12 / 2.6)	0.65 (−0.1 / 2.25)	.06
Overjet (mm)[c]	−2.3 ± 0.66	1.9 ± 2.4	4.2 (2.7 / 5.7)	$P < .01$

[a] IQR indicates interquartile range; mm, millimeter; CI, confidence interval.
[b] Variables presented as median and interquartile range (IQR).
[c] Variables presented as mean and standard deviation (SD).

comparable durations were observed when adjusted for this difference.

Vishnu et al.[15] compared three treatment modalities for AC, reporting durations of 3 weeks for 2 × 4 fixed appliances, and 8 weeks for the ZS appliance with weekly activation. Although fixed appliances yielded the shortest duration, they were associated with increased plaque accumulation. Due to their removable nature, ZS appliances required greater patient cooperation. These findings emphasize the need to balance treatment efficiency with patient adherence in appliance selection.

Treatment duration differences may also reflect variations in appliance design, activation, retention, malocclusion severity, and compliance. Clarifying the role of these factors requires further investigation and may contribute to more standardized approaches for AC correction.

At T0, there were no statistically significant differences between groups in cephalometric parameters, except for IMPA. However, this discrepancy was unlikely to influence treatment outcomes, as the interventions primarily targeted the maxillary incisors.

Table 6. Comparison of Cephalometric Measurement Differences (ΔT1-T0) Between Group A and Group B[a,b]

Variable	Group A	Group B	Difference (95% CI)	*P* Value
SNA (°)[a]	−0.6 (−1.5 / 1.32)	0 (−0.18 / 1.6)	0.8 (−0.8 / 2.8)	.21
SNB (°)[a]	−0.5 (−1.2 / 1.3)	0 (0 / 0.9)	0.6 (−0.8 / 1.9)	.47
ANB (°)[a]	−0.1 (−0.92 / 0.8)	0 (0 / 0.57)	0.1 (−0.8 / 1)	.72
Wits (mm) [a]	0.2 (−1.07 / 1.9)	0 (−0.68 / 0.7)	−0.1 (−1.8 / 1.4)	.86
FMA (°)[b]	−0.4 ± 2.8	−0.006 ± 2.75	0.39 (−1.7 / 2.46)	.69
SN-GoGn (°)[a]	0 (−0.28 / 1.5)	0 (−0.6 / 0.38)	−0.5 (−2 / 0.4)	.45
Interincisal Angle [b]	−4 ± 8	−5.3 ± 5	−1.24 (−6.2 / 3.75)	.61
U1-NA (°)[a]	5.3 (2.8 – 9.6)	7.6 (7.1 – 8.5)	2.3 (−0.1 / 4.8)	.06
U1-NA (mm) [b]	2.5 ± 3	3.4 ± 3.3	0.86 (−1.5 / 3.2)	.46
U1-Palatal Plane (°)[a]	4.9 (2.7 – 10.5)	6.3 (5.1 – 7.1)	1.3 (−4.4 / 3.7)	.49
L1-NB (°)[b]	−1 ± 3.2	−1.15 ± 2.4	−0.15 (−2.3 / 1.95)	.88
L1-NB (mm) [a]	−0.7 (−0.95 / −0.13)	0 (−0.65 / 0.35)	0.5 (−0.1 / 1.2)	.07
IMPA (°)[b]	−1 ± 3.1	−1.25 ± 3.2	−0.2 (−2.6 / 2.2)	.86
Nasolabial Angle [a]	0 (−0.18 / 10.5)	0 (0 / 1.9)	0.8 (−9.9 / 6.6)	.85
Upper Lip to S-Line (mm) [a]	0.9 (−1.3 / 1.2)	0 (−0.3 / 0.34)	−0.5 (−1.2 / 1.2)	.38
Lower Lip to S-Line (mm) [a]	−0.1 (−0.13 / 0.4)	0 (−0.73 / 0.75)	0 (−0.9 / 1)	.86
Overbite (mm) [a]	1.2 (−0.78 / 2.3)	0.4 (−0.2 / 1.4)	−0.1 (−1.5 / 1.5)	.93
Overjet (mm) [a]	4.4 (1.2 – 5.6)	4.8 (3 – 5.9)	0.6 (−1 / 2.3)	.53

[a] Variables presented as median and interquartile range (IQR).
[b] Variables presented as mean and standard deviation (SD).

Table 7. Comparison of Analog Model Analysis at T0 and T1 in Group A and Group B

Variable[a–c]	T0	T1	Difference (95% CI)	*P* Value
Group A				
Arch length[b] (mm)	72 (70.7–74.3)	73 (67.6–74.7)	0.45 (−2.25 / 1.15)	.57
Gingival arch depth[b] (mm)	21.8 (20.8–24)	23.7 (21.8–25)	1.17 (0.75–1.6)	$P < .01$
Incisal arch depth[c] (mm)	24.3 ± 2.5	26.86 ± 2.46	2.6 (1.76 / 3.46)	$P < .01$
Intermolar width[b] (mm)	50.9 (49.9–53.8)	50.7 (49.5–52.7)	−0.05 (−0.6 / 0.4)	.8
Incisor tipping amount[c] (°)	1.8 ± 1.35	3.3 ± 1.07	1.47 (0.7 / 2.2)	$P < .01$
Group B				
Arch Length[b] (mm)	73.5 (64.2–80.9)	73.9 (61.1–82.5)	0.40 (−3.1 / 1.6)	.71
Gingival Arch Depth (mm)[c]	23.2 ± 2.4	23.9 ± 2.3	0.67 (−0.64 / 2)	.29
Incisal Arch Depth[c] (mm)	25.8 ± 2.5	26.9 ± 2.8	1.08 (−0.36 / 2.5)	.13
Intermolar Width[c] (mm)	52.2 ± 2.9	51.9 ± 3.5	−0.3 (−0.84 / 0.24)	.25
Incisor Tipping Amount[c] (°)	2.57 ± 1.03	2.98 ± 1.46	0.41 (−0.37 / 1.20)	.28

[a] IQR indicates interquartile range; mm, millimeter; CI, confidence interval.
[b] Variables presented as median and interquartile range (IQR).
[c] Variables presented as mean and standard deviation (SD).

The U1-NA angle increased significantly in both groups, reflecting effective labial movement of maxillary incisors and sagittal correction. The greater increase in U1-NA observed in Group B may reflect a more pronounced tipping effect caused by ZS appliance mechanics. ZS appliances primarily induce tipping movements, while clear aligners facilitate a combination of tipping and bodily movement, which may have accounted for this variation.

The L1-NB distance decreased significantly in Group A but remained stable in Group B, suggesting a stronger retroclination effect of clear aligners, although the difference was not statistically significant. The interincisal angle decreased in both groups, with a less pronounced reduction in Group A, indicating a more upright incisor position. Overjet was corrected in both groups. Overbite increased significantly in Group A and approached significance in Group B, suggesting that both appliances corrected AC primarily through upper incisor movement rather than skeletal changes.

Miamoto et al.[16] reported upper incisor protrusion of 3.27° in a similar AC treatment study, whereas, in this study, greater protrusion of 7.6° was observed in the ZS group, likely due to differences in appliance design and force application. Their study also reported a reduction in arch length (−0.47 mm), while the present study observed a slight, nonsignificant increase (0.3 mm). In both groups, arch length was preserved. However, in Group A, posterior space may have been utilized for anterior alignment, with incisor protrusion compensating for this adjustment. This finding was consistent with the biomechanical principles of clear aligners, which often rely on posterior space utilization rather than arch expansion to achieve alignment.

Wiedel et al.[14] analyzed intermolar width changes, reporting a 0.6-mm increase for ZS appliances, whereas the current study found a non-significant −0.3 mm change. This difference may have stemmed from the presence of an expansion screw in their ZS appliance, which was absent in the design used in this study.

Both clear aligners and ZS appliances appeared to provide comparable benefits in terms of OHRQoL. Although ZS appliances were initially expected to negatively impact social-emotional well-being due to esthetic concerns, patient perceptions did not reflect this. This may be attributed to the short treatment duration and overall high satisfaction levels. Khalaf et al.[17] reported that removable appliances caused less discomfort than fixed appliances, whereas another review noted that clear aligners were often preferred for their esthetic appeal. However, the current findings suggested no clear quality-of-life advantage of clear aligners over ZS appliances, supporting the idea that both are well accepted by children.

Table 8. Comparison of Analog Model Analysis Measurement Differences (ΔT1-T0) Between Group A and Group B[a–c]

Variable	Group A Δ (T1-T0)	Group B Δ (T1-T0)	Difference (95% CI)	*P* Value
Arch Length[b] (mm)	0.9 (−0.8 / 1.17)	0.3 (−2.6 / 0.55)	−0.6 (−1.9 / 1)	.46
Gingival Arch Depth[b] (mm)	1.3 (0.48 / 1.6)	0.8 (−0.5 / 1.8)	−0.3 (−1.4 / 0.8)	.48
Incisal Arch Depth[c] (mm)	2.6 ± 1.5	1.08 ± 2.6	−1.5 (−3.1 / 0.08)	.06
Intermolar Width[b] (mm)	−0.1 (−0.5 / 0.5)	−0.3 (−0.98 / 0.2)	−0.3 (−0.9 / 0.5)	.49
Incisor Tipping Amount[c] (°)	1.47 ± 1.4	0.41 ± 1.42	−1.05 (−2 / −0.009)	.04

[a] CI indicates confidence interval.
[b] Variables presented as median and interquartile range (IQR).
[c] Variables presented as mean and standard deviation (SD).

Table 9. Comparison of Treatment Protocols Between Group A and Group B in Terms of COHIP-SF-19 Total Score and Subscores[a–c]

Variable	Group A	Group B	Difference (95% CI)	*P* Value
COHIP-SF-19 Score[c]	15 ± 5.6	14 ± 8.3	1 (−6.3 / 4.3)	.70
Oral Health (IQR)[b]	5 (4–6)	5 (3.25–6.75)	0 (−2 / 1)	.55
Functional Health (IQR)[b]	2 (1.25–5)	3 (2–5.75)	1 (−1 / 2)	.29
Social-Emotional Well-being (IQR)[b]	6 (4–7)	2 (1–10)	2 (−5 / 3)	.53

[a] Mean indicates average; SD, standard deviation; CI, confidence interval; IQR, interquartile range.
[b] Variables presented as median and interquartile range (IQR).
[c] Variables presented as mean and standard deviation (SD).

CONCLUSIONS

- Both aligners and z-spring appliances effectively corrected AC, achieving normal overjet relationships. Dentoalveolar changes were observed during treatment, whereas skeletal relationships and natural growth remained unaffected.
- Clear aligners required a significantly longer treatment duration than ZS appliances, with an average difference of 47.9 days. Longer treatment durations in removable appliances may negatively affect patient compliance and increase the risk of treatment discontinuation. Treatment selection should be made in collaboration with parents and clinicians.
- The impact of age on treatment duration was not statistically significant. However, younger patients (7–10 years) showed greater variability, whereas older patients (>10 years) had a more consistent but slightly longer duration.
- This study compared treatment outcomes and OHRQoL, showing that clear aligners offer esthetic and comfort benefits, whereas ZS appliances provide a cost-effective, efficient alternative. Treatment selection should consider patient preferences and clinical needs.

SUPPLEMENTAL DATA

Appendix #1 is available online.

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ÖEG and AYG conceived the study design and provided oversight throughout the research process. ÖEG served as the corresponding author, ensuring effective communication with the journal and addressing editorial requirements. Additionally, ÖEG and AYG contributed to the refinement of the manuscript, providing critical academic insights and ensuring alignment with the study's objectives. BNG was responsible for performing the treatments, collecting, organizing, and analyzing the data, preparing the tables and figures, and drafting the manuscript. Statistical analyses and data interpretation were primarily handled by BNG, with guidance from ÖEG. All authors participated in reviewing the final version of the manuscript and approved it for submission.

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DISCLOSURES

The data supporting this study's findings are registered on ClinicalTrials.gov under the identifier [NCT06792513]. While privacy and ethical restrictions prevent public access to the data, researchers meeting the criteria for access to confidential data may request the datasets from the corresponding author. All requests will be reviewed in accordance with ethical guidelines and privacy protocols. Additionally, supplementary data that do not compromise confidentiality may be shared in a de-identified format to promote transparency and support further research in this field.

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The authors declare that there are no conflicts of interest associated with this study. Neither the authors nor their affiliated institutions have received any financial or personal benefits that could influence the study's outcomes. This research aims to present its findings in an unbiased manner and solely for academic and clinical advancement.

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